AFRL-RW-EG-TP-2014-003

Damage-Sensitivity Correlations in Explosives

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July 2014

Interim Report

AIR FORCE RESEARCH LABORATORY, MUNITIONS DIRECTORATE

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
25-07-2014

2. REPORT TYPE
Interim

3. DATES COVERED *(From - To)*
1 October 2011 – 30 November 2013

4. TITLE AND SUBTITLE
Damage-Sensitivity Correlations in Explosives

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
61102F

6. AUTHOR(S)
George Sunny, Thomas Krawietz, Chad G. Rumchik, Jennifer Jordan, John Cox

5d. PROJECT NUMBER
3002DW32

5e. TASK NUMBER

5f. WORK UNIT NUMBER
W0A7

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory
Munitions Directorate
Ordnance Division
Energetic Materials Branch
Eglin AFB, FL 32542-5910

8. PERFORMING ORGANIZATION REPORT NUMBER
AFRL-RW-EG-TP-2014-003

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory, Munitions Directorate
Ordnance Division
Energetic Materials Branch (AFRL/RWME)
Eglin AFB FL 32542-5910
Technical Advisor: Dr. C. Michael Lindsay

10. SPONSOR/MONITOR'S ACRONYM(S)
AFRL-RW-EG

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AFRL-RW-EG-TP-2014-003

12. DISTRIBUTION / AVAILABILITY STATEMENT

Distribution A: Approved for public release; distribution unlimited. Approval Confirmation 96 ABW/PA # 96ABW-2013-0209, dated 9 August 2013

13. SUPPLEMENTARY NOTES

DISTRIBUTION STATEMENT INDICATING AUTHORIZED ACCESS IS ON THE COVER PAGE AND BLOCK 12 OF THIS FORM.

14. ABSTRACT
As energetic materials are subjected to increasingly extreme environments, the effects of damage on changes in sensitivity at a fundamental level need to be better understood. To that end, a variety of experiments have been conducted on a plastic-bonded explosive. Shock Wave Apparatus (SWA) and Modified Gap Tests (MGT) were conducted based on similar tests performed at Gesellschaft für verteidigungstechnische Wirksysteme (TDW). X-Ray Computed Microtomography (XCMT) was conducted on the damaged explosive and the results analyzed using a MATLAB routine which quantified damage in the samples. In addition, a series of confined Split- Hopkinson Pressure Bar (SHPB) tests have been performed on an explosive simulant to understand the effects of confinement on the polymer binder and simulant, as the polymer binder exhibits substantial pressure sensitivity. SWA and MGT results suggest that damage increases sensitivity for initiation pressures below 3.5 GPa, while for pressures above 3.5 GPa the sensitivity of the explosive remains largely unchanged. Results from quantification of the XCMT images show that the distribution of void size appears to be the primary difference between the damaged and pristine explosive. Results from the confined SHPB tests show an increase in the true stress from about 3 MPa (unconfined) to 50-80 MPa (aluminum confinement) on the simulant at strain rates of about 500/s; aluminum confinement of the binder increases the stresses achieved from approximately 1 MPa (unconfined) to in excess of 80 MPa. The increase in stress is accompanied by the introduction of axial cracking (similar to ceramics) as a failure mechanism.

15. SUBJECT TERMS
Damage, pressure-sensitivity, strain rate-sensitivity, Split-Hopkinson Pressure Bar, explosive sensitivity

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					George Sunny
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(include area code)*
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL	29	850-882-1462

Standard Form 298 (Rev. 8-98)
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Damage-Sensitivity Correlations in Explosives

15 October 2013

George Sunny, Thomas Krawietz, Chad Rumchik, Jennifer Jordan, John Cox

Energetic Materials Branch

Air Force Research Laboratory

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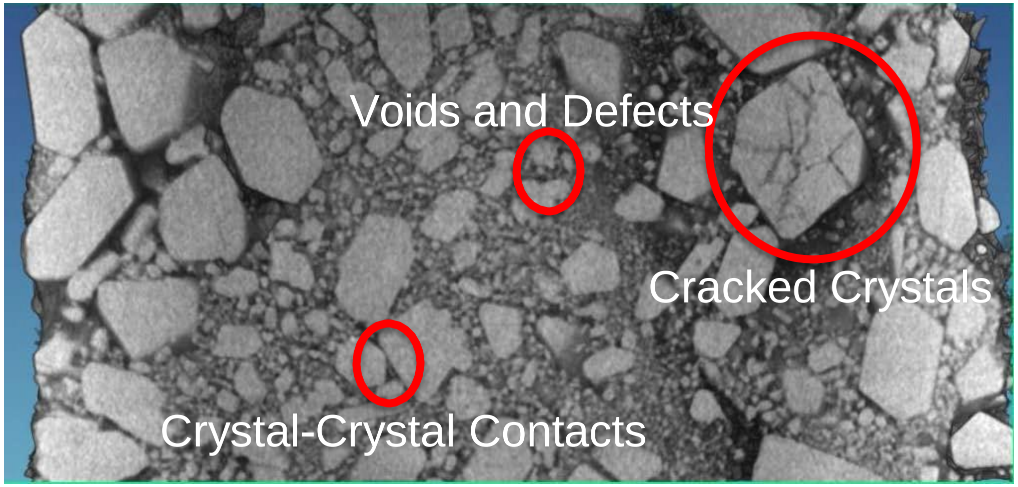
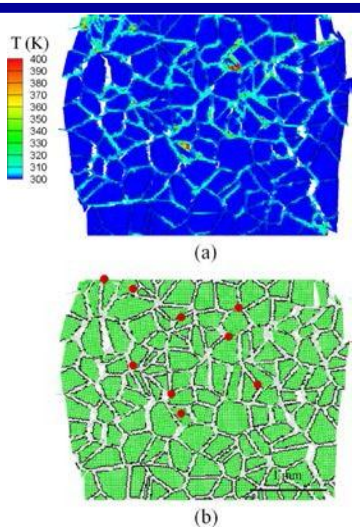
Overview

- Basic Principles: Damage in Explosives
- Experiments
  - Split-Hopkinson Pressure Bar
  - Shock Wave Apparatus
  - Modified Gap Test
- Non-destructive Imaging of Explosive
- Damage Quantification Methods
- Future Work

Composite Explosive

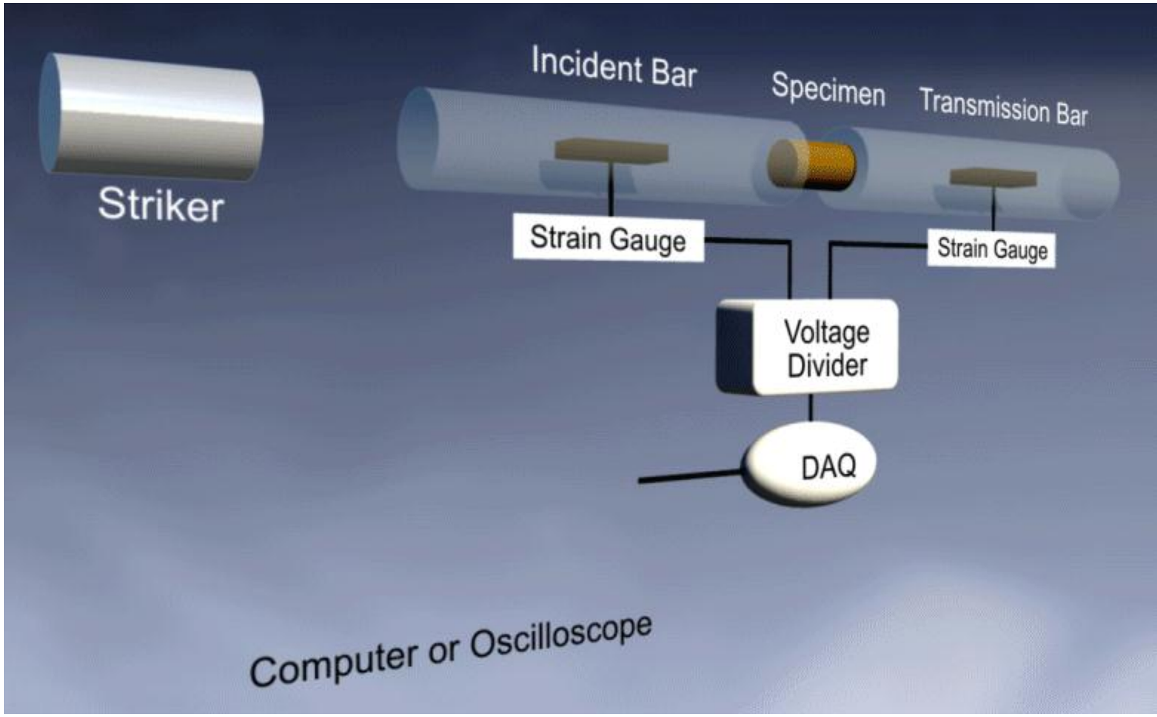




- Experimental Observations (Field)
  - “Adiabatic compression of trapped gas spaces”
  - “Other mechanisms involving cavity collapse such as viscous or plastic heating of the surrounding matrix material”
  - “Friction between sliding or impacting surfaces, or between explosive crystals and/or grit particles in an explosive”
  - “Localized adiabatic shear of the material during mechanical failure”
- Mesoscale Simulations (Barua)
  - Strong dependence on volume fraction of particulates
  - Viscoelastic dissipation in binder → temperature rise
  - Grain-matrix debonding, binder tearing → damage
  - Grain-grain contact → fracture and frictional dissipation

A. Barua, Y. Horie, and M. Zhou, “Energy Localization in HMX-Estane polymer-bonded explosives during impact loading,” *Journal of Applied Physics*, **111**, 054902 (2012)
J.E. Field, “Hot Spot Ignition Mechanisms for Explosives,” *Accounts of Chemical Research*, **25**, 489-496 (1992).

Split-Hopkinson Pressure Bar

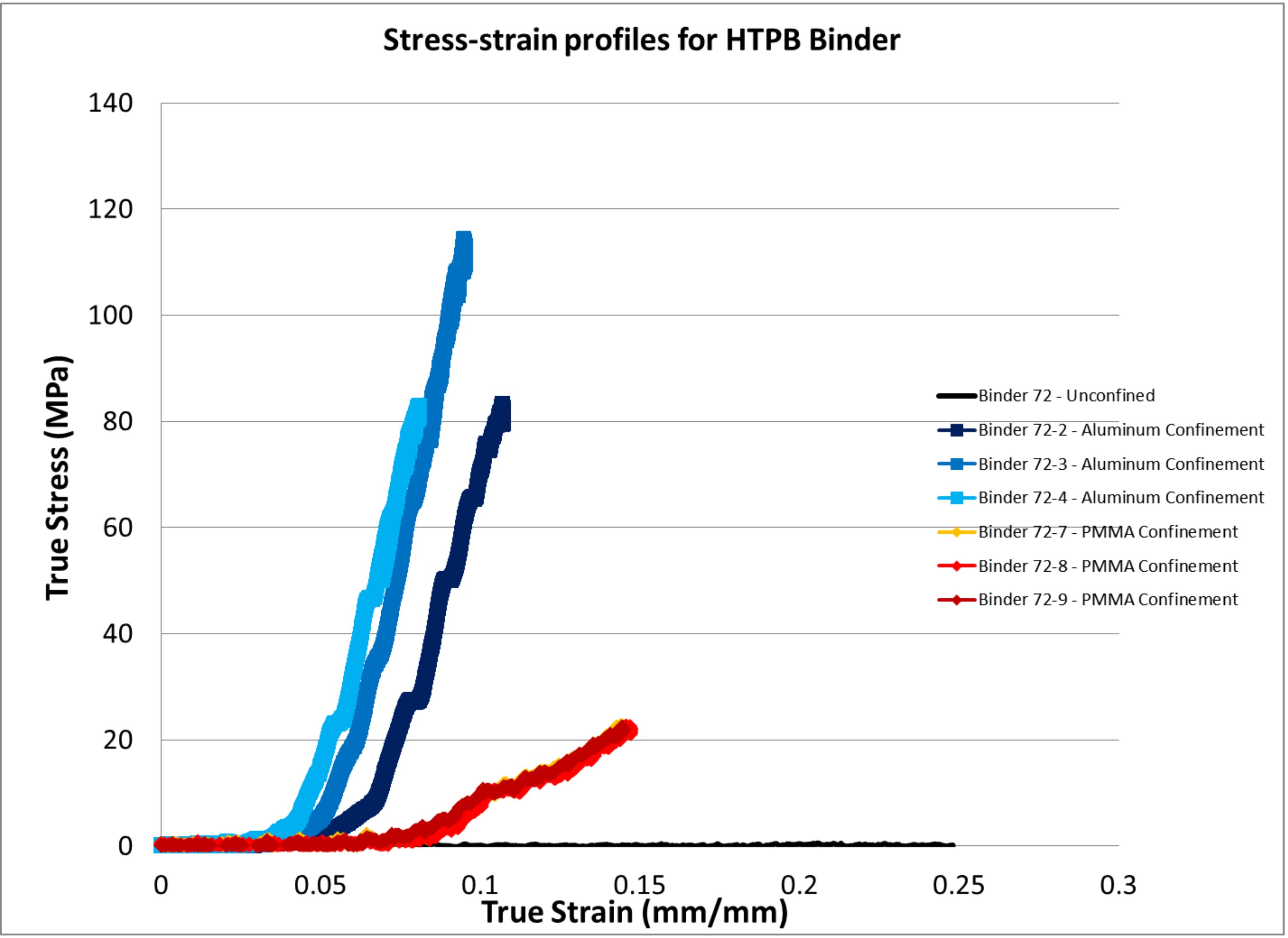


- Use of confining ring to apply pressure
  - PMMA (1/8" thick)
  - Aluminum (1/4" thick)

Split-Hopkinson Pressure Bar

- Use of confining ring to apply pressure
  - PMMA, aluminum
  - Mandates the use of samples with same diameter as bars (19 mm)

Split-Hopkinson Pressure Bar



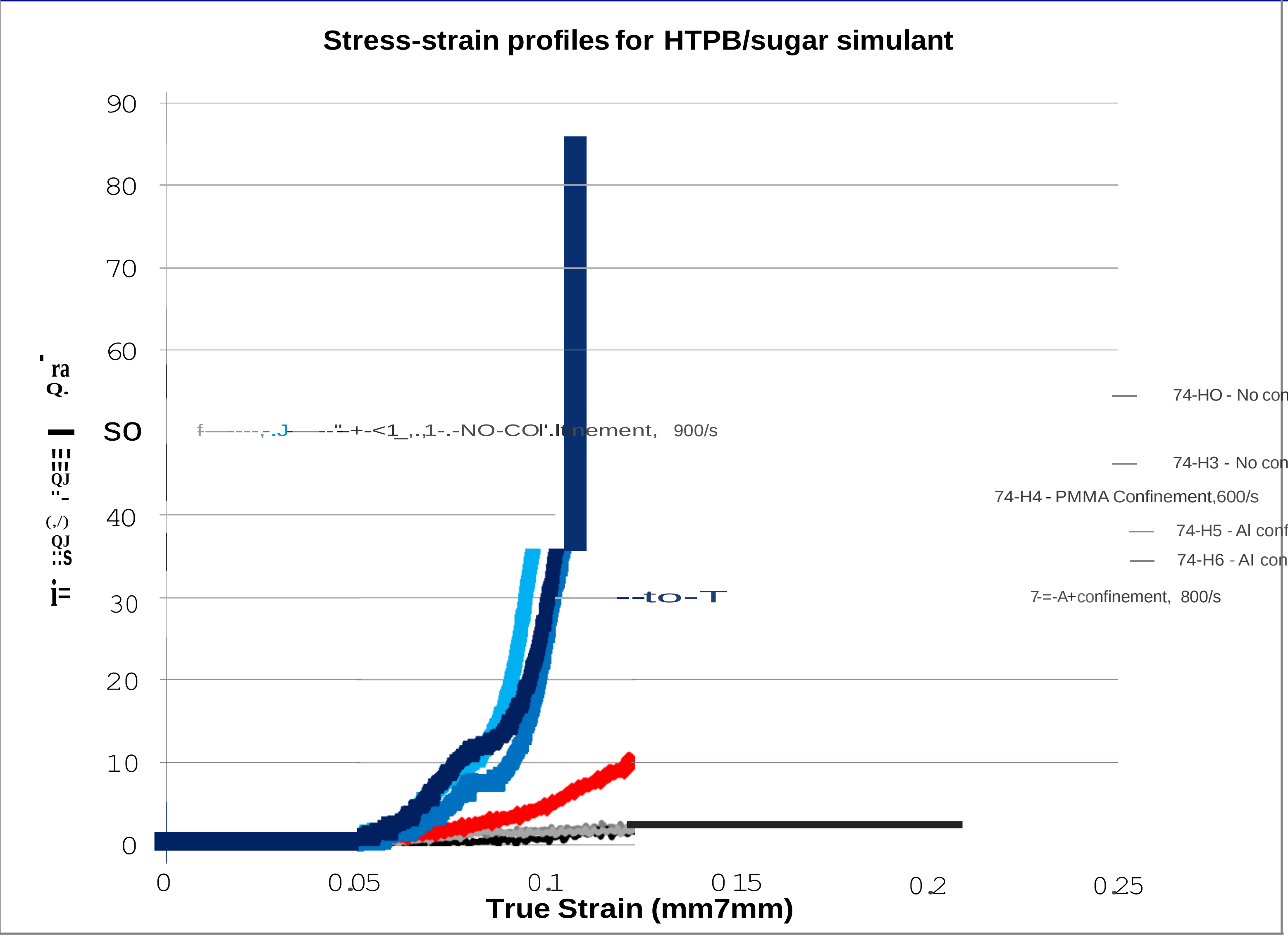
Strain-rate of all samples about 750/s, except for unconfined (black), at 1250/s

Estimated radial stresses:

Al: 20 MPa

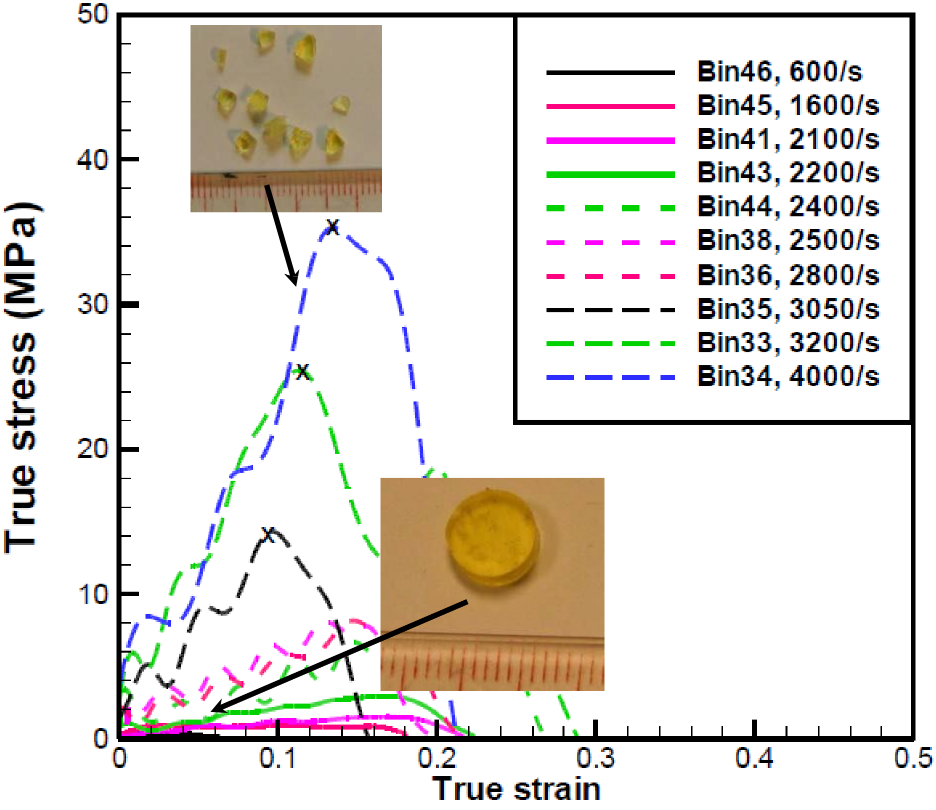
PMMA: 2 MPa

Split-Hopkinson Pressure Bar

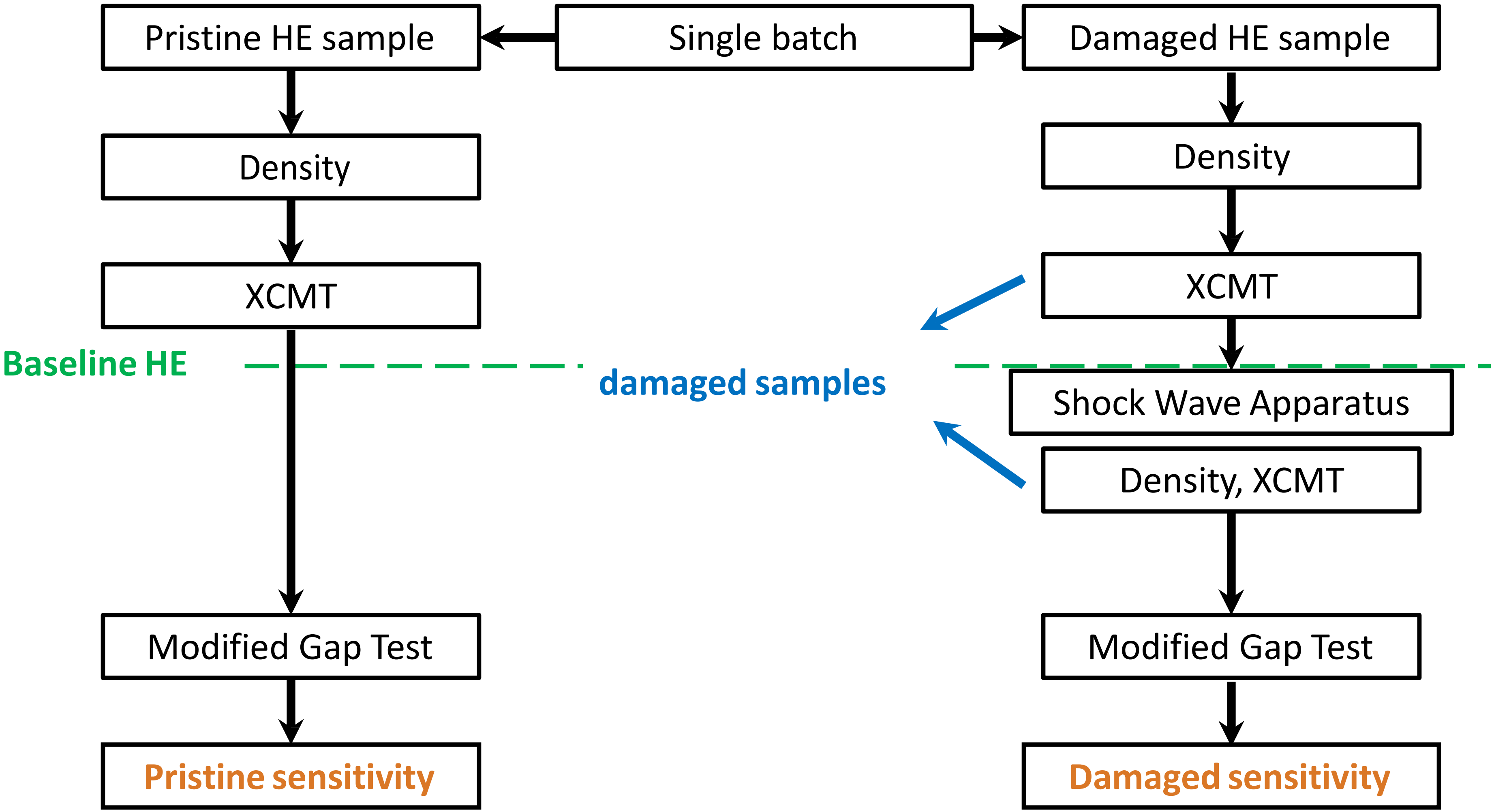


Split-Hopkinson Pressure Bar

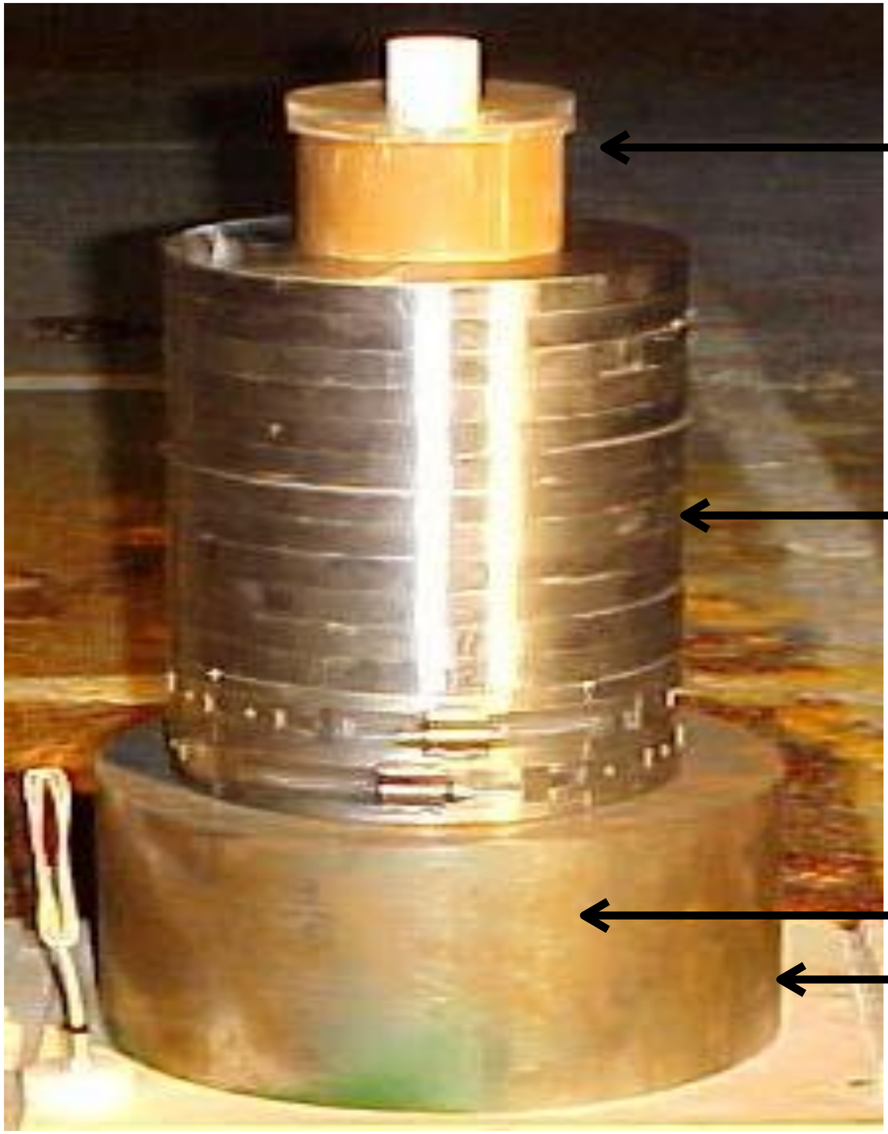
- Samples after testing
  - Largely go back to their original cylindrical shape
  - Some damage previously seen in binder at highest strain-rates (3000/s)
  - Strong rate and pressure sensitivity



Ideal Testing Process



Shock Wave Apparatus



Shock pressures: 0.5 GPa

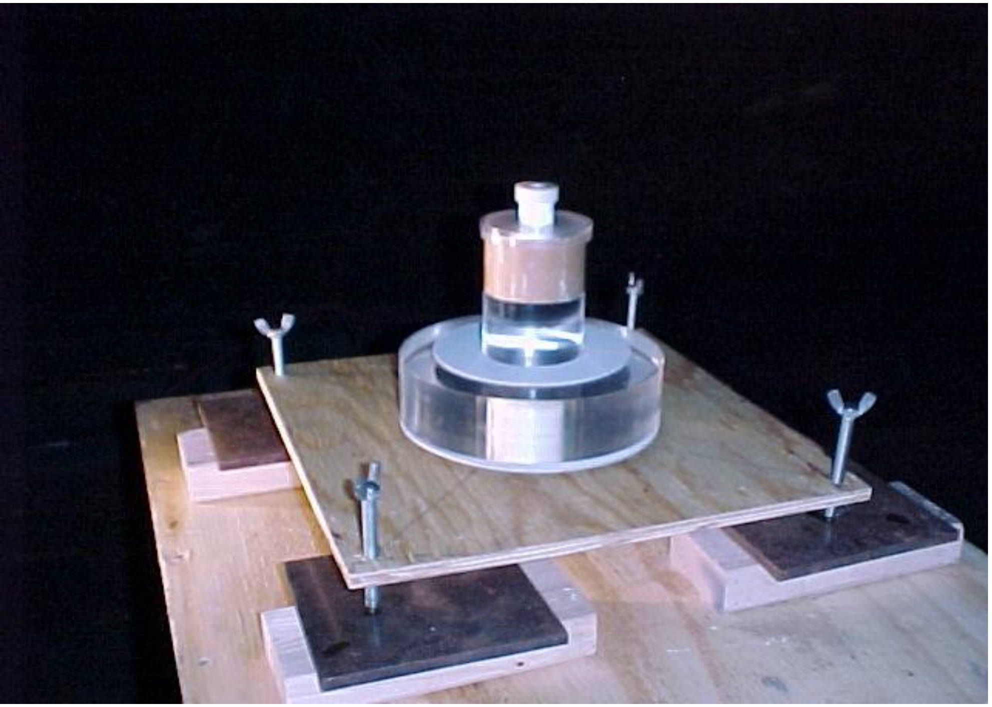
Donor explosive

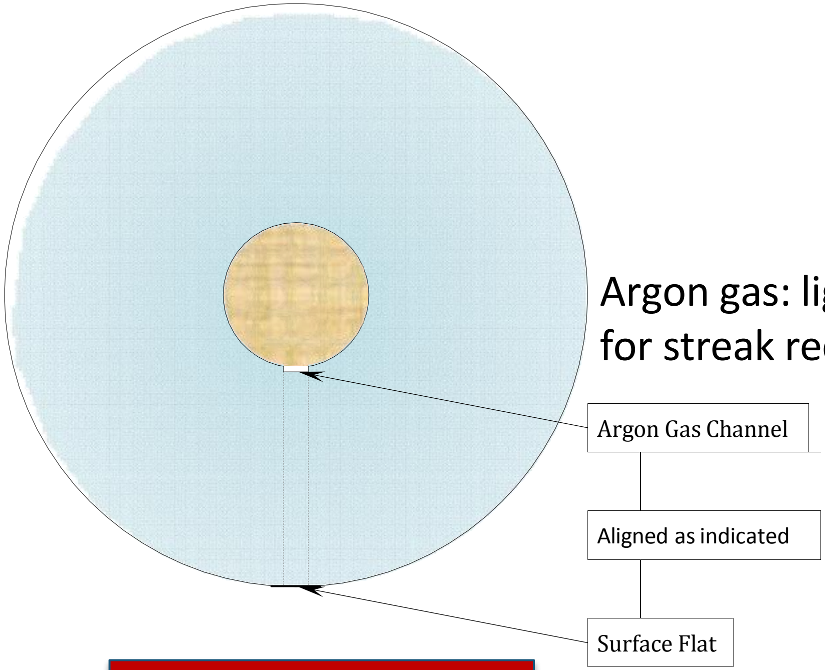
Steel plates

Explosive of interest

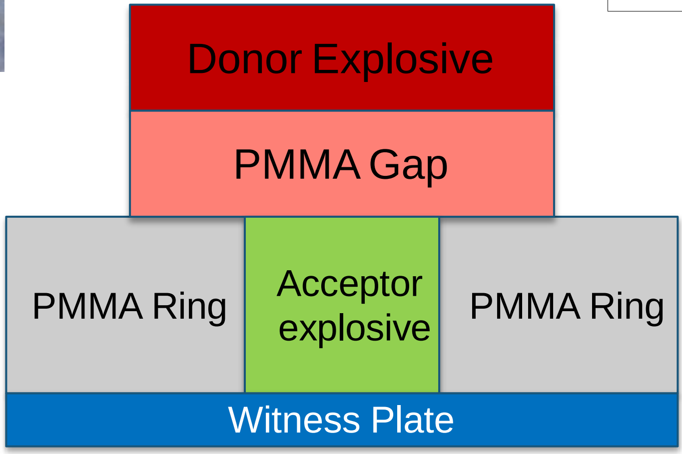
Steel confining ring

Modified Gap Test



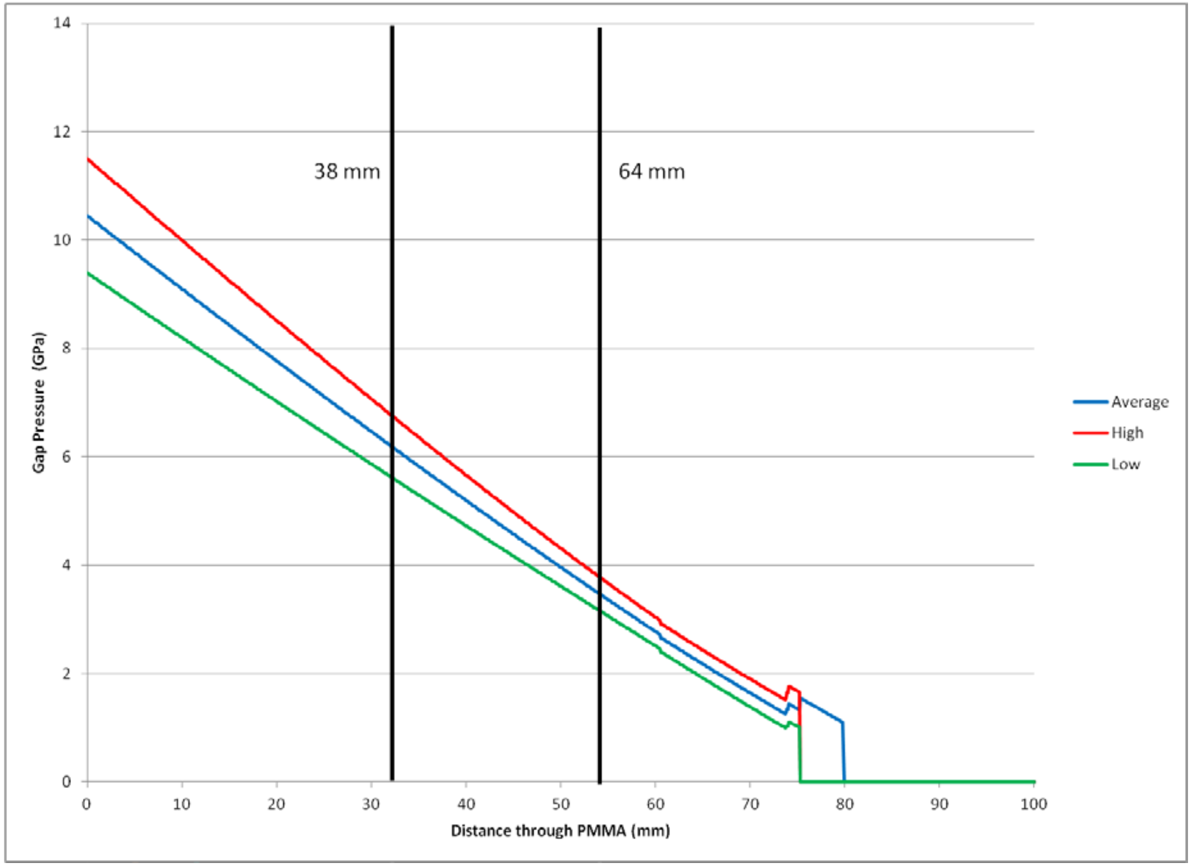


- Assumption
  - Run-to-detonation (RTD) on outside is representative of RTD in interior of charge



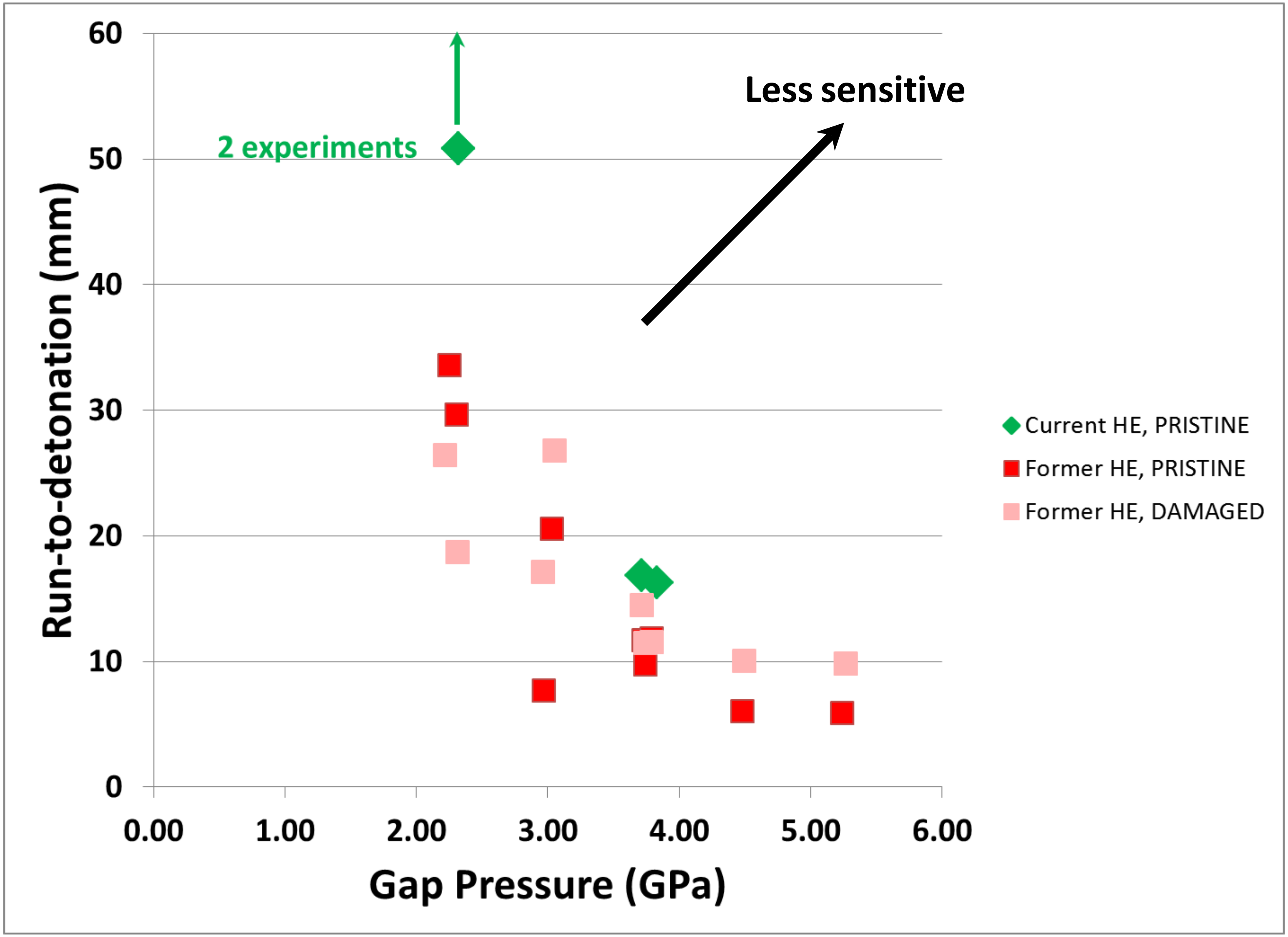
Modified Gap Test

- Calibration



Errors in calibration are about 10% for normal PMMA gaps (38-64 mm)

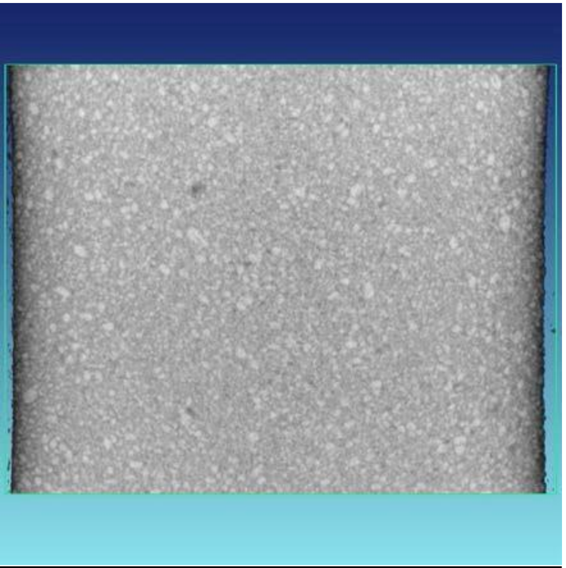
Sensitivity of Explosive



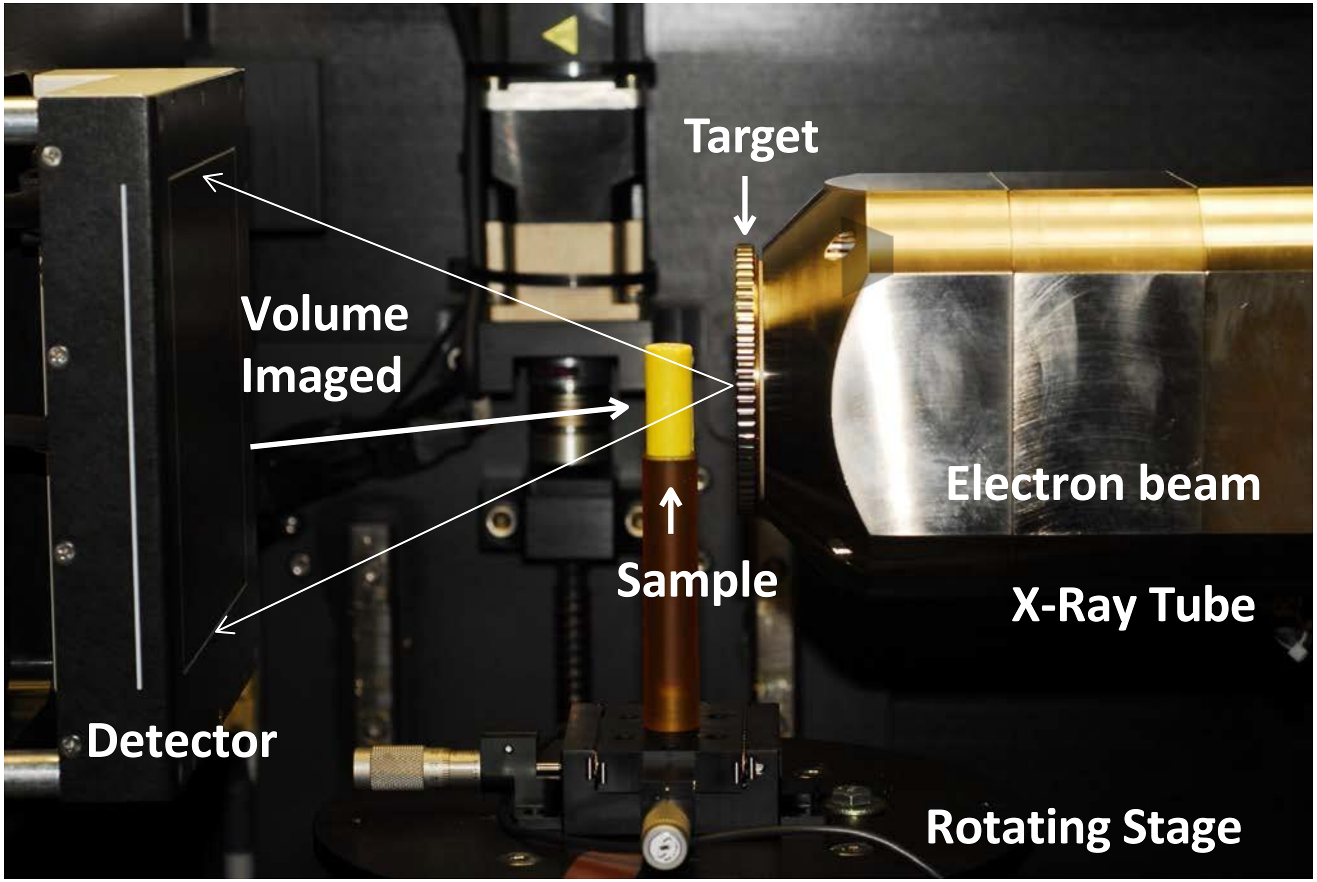
Sensitivity of Explosive

- Current HE appears to be less sensitive
- Differences most prominent at lower pressures
  - Negligible differences between pristine and damaged at higher pressures
  - Uncertainty of 2 mm in RTD
- Some scatter in the data

XCMT Imaging

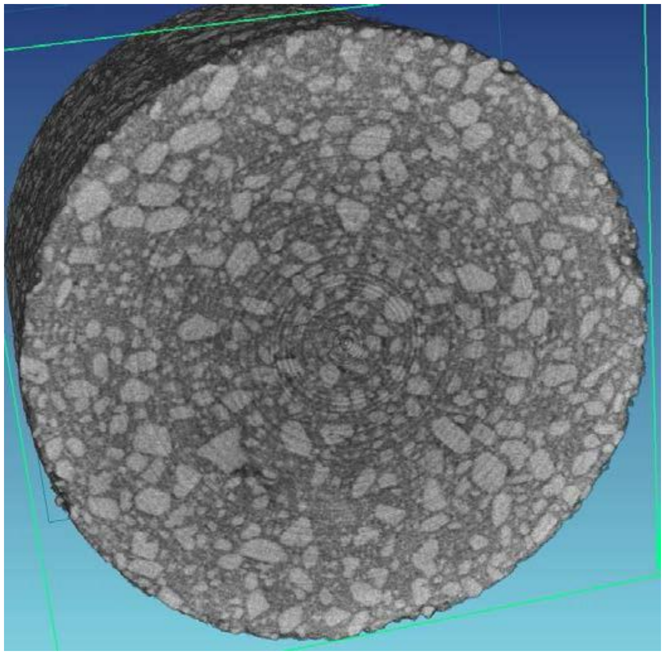


- Pristine PBX for current study, relatively free of voids (grey circles)



Damage of Explosive

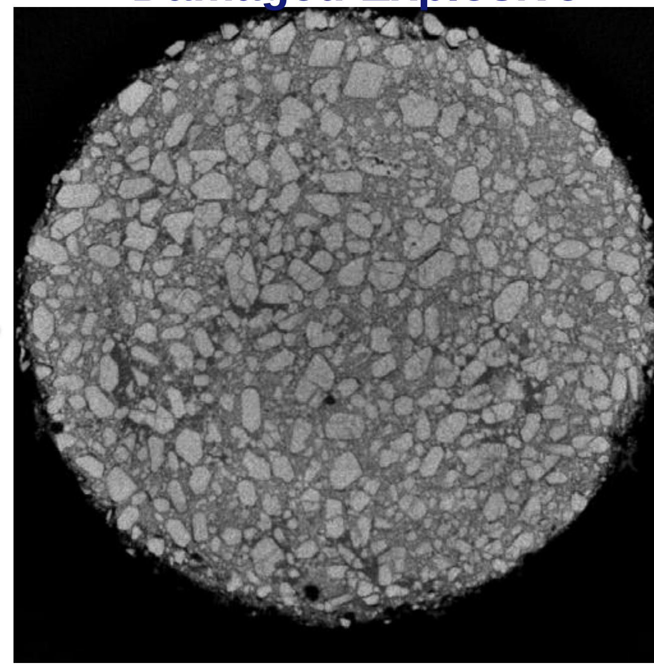
As Processed Explosive



0.5-inch diameter core
Target: Al 50kV, 178 μA
0.5 fps, 5 frames/view
720 views

Explosive loading at ~0.5 GPa

Damaged Explosive

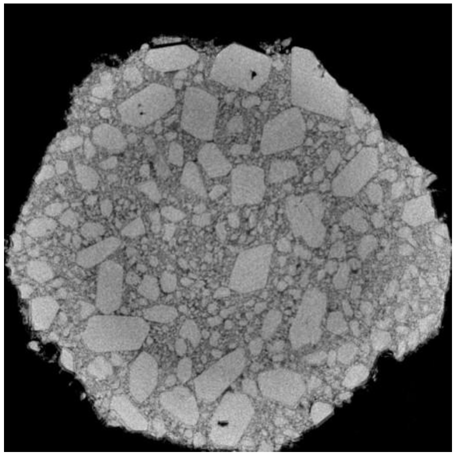


0.5-inch diameter core
Target: W/diamond 45kV, 300 μA
1 fps, 2 frames/view
1440 views

Test sample is 2" in diameter. XCMT sample is cored from test sample.

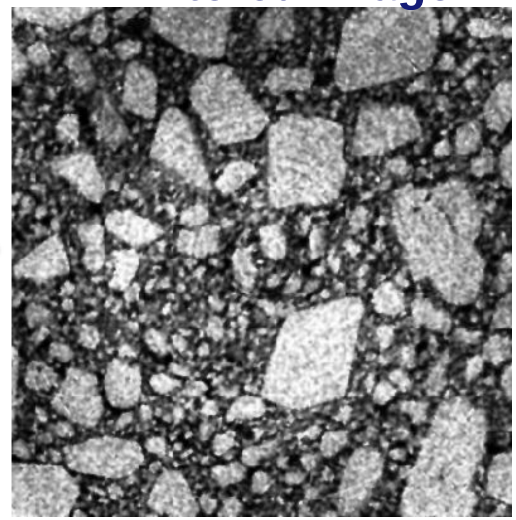
Analysis of XCMT Images

Original Microstructure

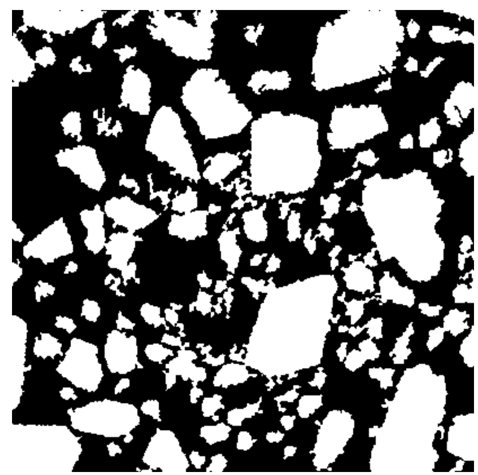


Select center of image, apply filters

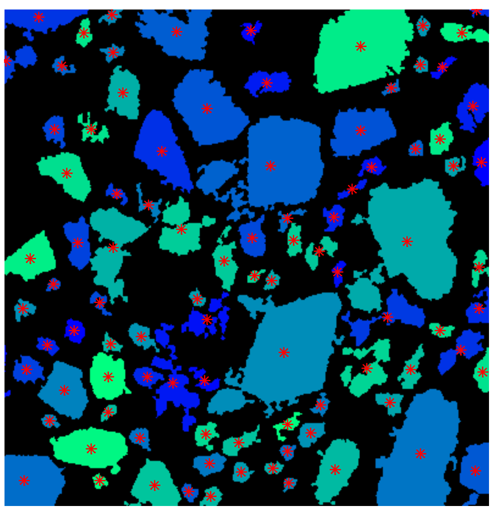
Filtered Image



Convert to Binary

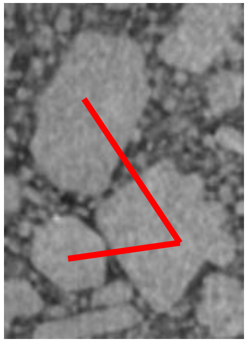
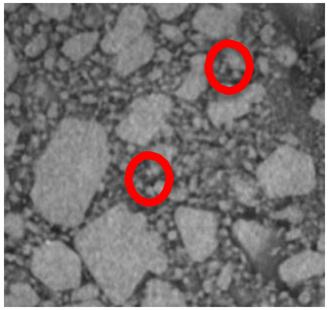
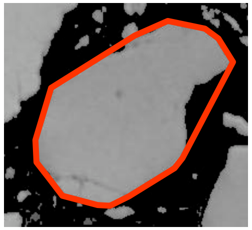
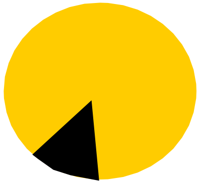


Particle Statistics

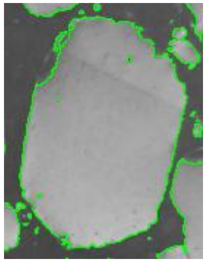
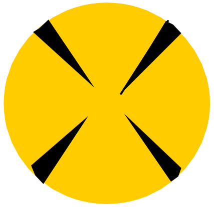


Key particle statistics

- Particle size distribution
- Spacing between grains
- Void volume fraction
- Void size distribution
- Convexity by perimeter/area

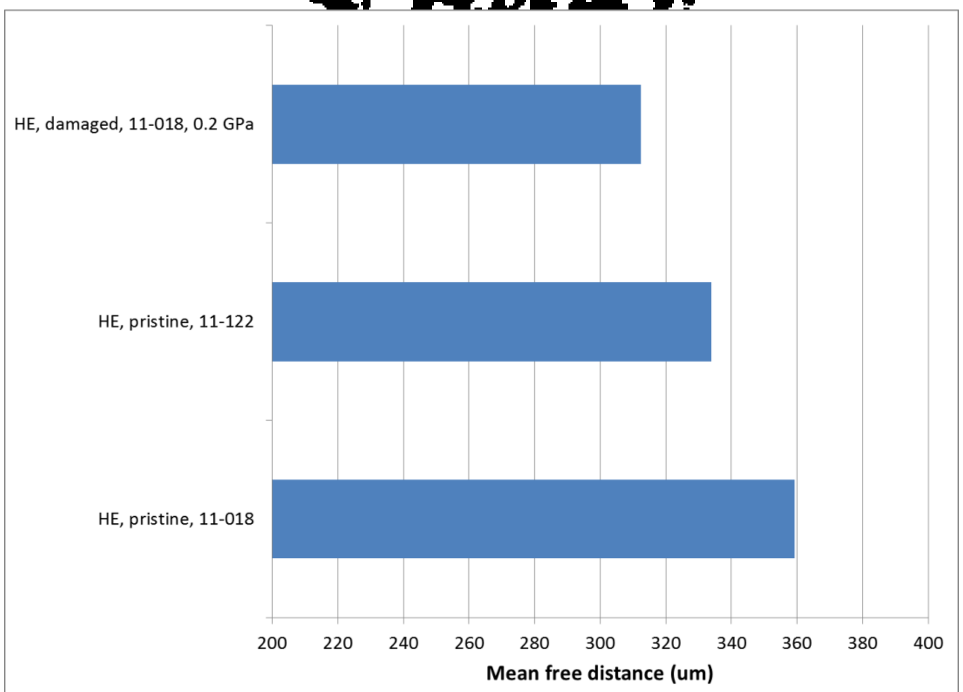
$C < 1$
$\xi \sim 1$

$\xi < 1$
$C \sim 1$

W.A. Arnold, “TDW Lessons Learned and Status 2011,” Presentation at US/DEU Bilateral Workshop, October 2011.

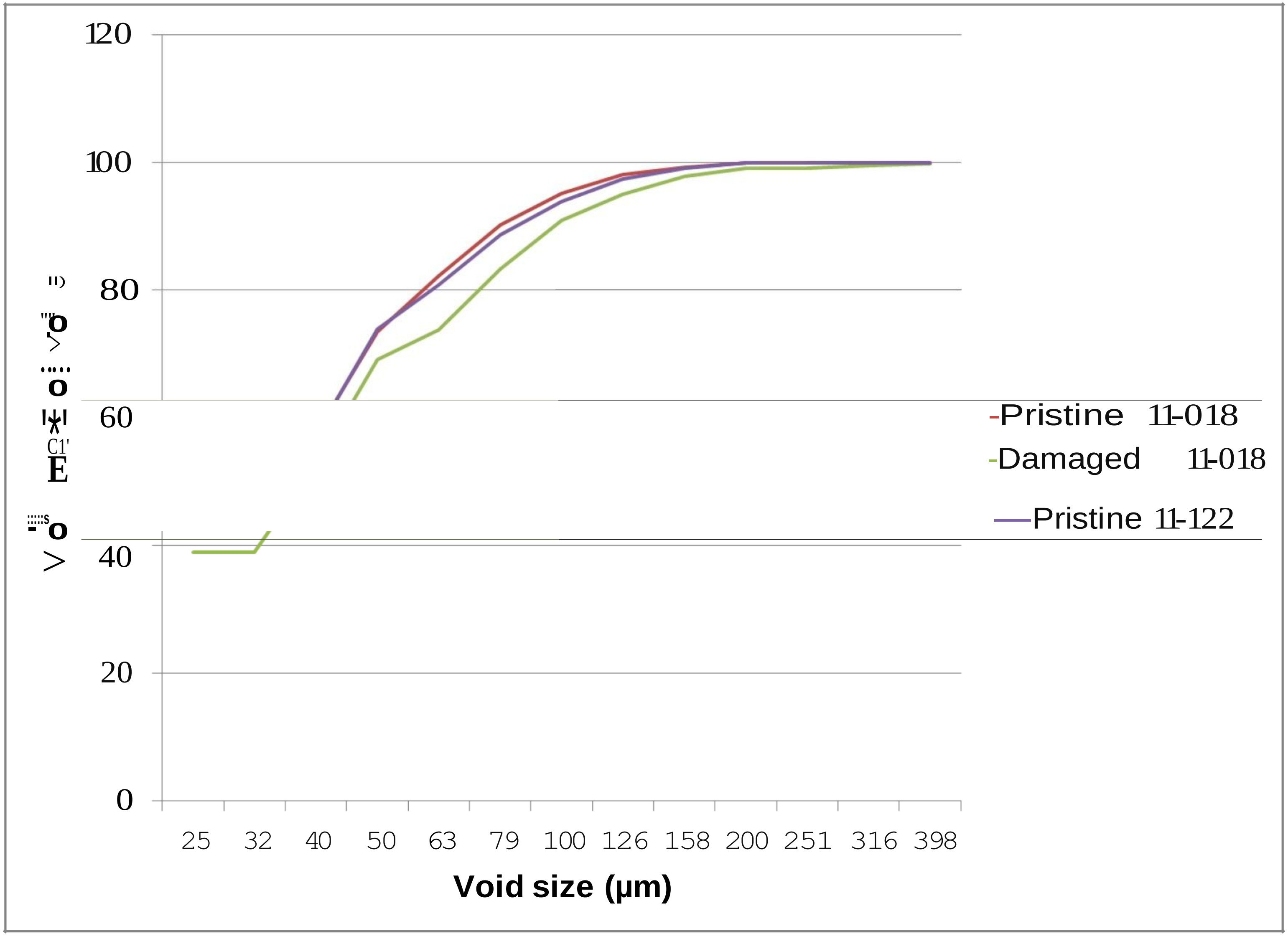
Mean Free Distance



- Distance between particle boundaries through matrix
- Captures distance between particles indicative of regions of friction or sliding and hot spot generation
- Particles in new batch of explosive and damaged explosive are closer together than in original batch

E.E. Underwood, *Quantitative Stereology,* Reading, MA: Addison-Wesley Publishing Company, p. 82-83 (1970).

Void Size Distribution



Future Work

- Compare pristine, damaged simulant samples
- Confined SHPB experiments on HE
  - Determine change in microstructural metrics
- Complete Modified Gap Tests on new HE
  - Shock Wave Apparatus experiments completed

Acknowledgments

- AFOSR
  - Dr. David Stargel, Dr. Jennifer Jordan
- AFRL
  - Dr. Eric Welle, Dr. Martin Schmidt, Mr. Didier Montaigne
- TDW (Germany)
  - Dr. Werner Arnold

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